Division of Industrial Hygiene
GEORGIA DEPARTMENT OF PUBLIC HEALTH
In Cooperation With
Georgia Institute of Technology
STATE ENGINEERING EXPERIMENT STATION
Atlanta, Georgia

FINAL REPORT

PROJECT NO. M-130

GRANT-IN-AID RG 2086

CARBON MONOXIDE GENERATION BY SPACE HEATERS IN TIGHTLY SEALED ROOMS

Prepared for

NATIONAL INSTITUTES OF HEALTH
UNITED STATES PUBLIC HEALTH SERVICE

By

ROBERT H. BYERS

OCTOBER 19, 1950

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TABLE OF CONTENTS

This Report Contains 29 Pages

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I. SUMMARY

A study has been made of the combustion products produced by gas space heaters when used in a small, tightly sealed room which had no outside ventilation. Liquefied petroleum gas and natural gas were used as the fuels, and both vented and unvented heaters were tested. Results indicate that a critical relationship exists between the rate of heating and the generation of carbon monoxide. The unvented heaters produced dangerous amounts of carbon monoxide, while the vented heaters were found to be safe when correctly vented, but were equally as dangerous as the unvented heaters when improperly vented.

II. INTRODUCTION

In the state of Georgia in recent years, a number of deaths have occurred in tourist cabins in which gas space heaters were used. The aim of this project was to measure the quantity of carbon monoxide contained in gases emitted by various types of gas space heaters. Results of the experiments will be used as a guide for the State Health Department in setting standards for the heating equipment used in tourist courts. The problem of dangerous combustion products from the use of such heaters in rooms of small volume is of growing concern, because of a rapid increase in the use of gas for heating and a change in the type of building construction.

As a first step in drafting the needed regulations, a search was made of the literature in this field; however, it was found that the most recently published data were those of a 1923 investigation of the Bureau of Mines. Moreover, the heaters tested at that time are now obsolete, and no tests were made on such "newer" fuels as the liquefied petroleum gases.

To obtain the necessary information, therefore, the Division of Industrial Hygiene of the Georgia Department of Public Health, in co-

operation with the Georgia Tech Engineering Experiment Station, undertook an investigation similar to the 1923 investigation by the Bureau of Mines, but using modern burners and both natural gas and liquefied petroleum gases. This study was sponsored in part by a grant-in-aid from the National Institutes of Health.

III. EXPERIMENTAL WORK

A room 12-1/2 x 10 x 8 feet (1,000-cubic-foot content) was constructed using wall board and 2 x 4-inch framing. This room was made as gas-tight as practical; the outside was sealed with tape, and the inside joints were caulked. The entrance doors were weather-stripped and were tightly sealed by bolting.

For heating this room, six gas space heaters were selected as typical of the types used in tourist courts in this area. Of these, four were unvented and two were vented. The heaters selected were:

Heater A. This was a radiant unvented heater with an orifice for liquefied petroleum gases. The radiants were completely enclosed by a cabinet, and the front was protected by a substantial grill. This heater was designed to prevent contact with the open flames, and from that standpoint is excellent in design.

Heater B. This was a radiant, unvented heater of more open construction than Heater A, with an orifice for liquefied petroleum gases. The cabinet was similar to that of Heater A, but the front grill was less substantial. This particular heater was of an unusual burner design in that individual orifices and venturi air mixers were supplied for each radiant. This type of heater is adjusted at the factory, and no air adjustment is possible in the field. The burner tips were made of a ceramic material.

Heater C. This was an unvented, steam radiator having an orifice for liquefied petroleum gases, and fired by a burner at the bottom. Because

of the high initial cost of this type of heater, small units are usually installed; therefore, a heater of approximately one half of the heat capacity of the other unvented heaters was tested.

Heater D. This was an open, radiant, unvented heater with an orifice for natural gas. There was no cabinet, and only a rather flimsy wire grill was used to prevent direct contact with the radiants.

Heater E. This was a totally enclosed radiant heater employing liquid petroleum gases. The front was covered by mica, and the flue gases were vented through a heat exchanger.

Heater F. This was a steam radiator, similar to Heater C except that the flue products were vented. It also was equipped for burning liquid petroleum gases.

The unvented heaters were operated in the sealed room, in which the air was mixed by a small electric fan. (Tables I through IV and Plots 2 through 5 in Appendices B and C refer to these tests.) A study of the air currents in the room was made by using smoke tubes in order to avoid as much as possible any direct influence on the heater performance by the fan.

Samples of air taken from the geometric center of the room were analyzed at intervals until the carbon monoxide content of the air reached 0.1 per cent, or until the gas flame went out. This percentage of carbon monoxide was chosen because, as may be seen from Plot 1 (Appendix C), exposure of a human being to this concentration for less than two hours could result in sufficient combination of blood haemoglobin with carbon monoxide to be fatal. These air samples were analyzed specifically for carbon monoxide, carbon dioxide, and oxygen content. The carbon monoxide content was determined colorimetrically by use of the carbon monoxide-detecting tubes developed by the National Bureau of Standards. The samples

of air were first measured in the burette tube of an orsat apparatus and then passed at a specified speed through a carbon monoxide-detecting tube.

A precision laboratory orsat apparatus, a modification of the Bureau of Mines instrument, was used for the determination of the carbon dioxide and oxygen contents of the air.

The rate of gas consumption by the heaters was measured by a wet test gas meter, and the gas pressure was checked by a manometer.

Tests on the vented heaters were of a nature similar to those on the unvented heaters, although made under somewhat different conditions. (The data of these tests are presented in Tables V through IX and Plots 6 through 9.) First, the heater was tested in the room without a vent. Next, a test was made after a vent pipe was connected to the heater and the combustion products conducted outside of the sealed room. A third test was made on one type of heater with the vent pipe lifted two feet above the vent collar of the heater. In this case the vent pipe could either vent the waste products or admit fresh air to the sealed room.

Commercial propane as sold in the Atlanta area was used as the fuel in all the tests but one in which natural gas was used for the purpose of demonstrating that the problem is common to all gas heaters, regardless of the type of fuel used.

For all calculations, 2,500 BTU per cubic foot was used for the heating value of the propane, and 1,000 BTU per cubic foot for the natural gas.

A number of variables governed the amount of carbon monoxide produced by the unvented heater. In general, only small amounts of carbon monoxide were produced as long as the room oxygen was above 17 per cent. As the amount of oxygen in the room decreased, the open-type heaters allowed the

flame to reach out for more oxygen. This extended flame eventually floated off the heater and was extinguished.

In the enclosed type of unvented heater, the flame was retained in the heater and continued to generate carbon monoxide for much longer periods without being extinguished.

The manner in which the primary air and the fuel are mixed also influences the carbon monoxide generation. The burners which were precisely made and of substantial construction gave off less carbon monoxide than those of cheaper type construction.

IV. CONCLUSIONS

From the results obtained with unvented heaters, it was concluded that all of the unvented types tested represent a definite hazard and should not be used in small rooms. This held true whether liquefied petroleum or natural gas was used as the fuel.

The performance of heaters vented outside the room was excellent. However, it should be noted that these tests were carried out under ideal conditions, i.e., the heater vent, which had no restrictions or raincap, was discharging into still air without influence of rain or other weather factors.

The tests on the vented heaters, including one test with no outside vent and another with a section of the vent pipe removed, proved that this type of heater can be fully as hazardous as the unvented heater, when the combustion products are not properly vented.

A relationship appears to exist between the rate of heating and the amount of carbon monoxide generated, as shown by the performance of the

small gas steam heater (unvented) which had the smallest BTU output. (See Table III and Plot 4 of Appendices B and C.)

Respectfully submitted:

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Robert H. Byers,
Project Director

Approved:

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State Engineering Experiment Station

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Lester M. Petrie, M. D., Director
Division of Industrial Hygiene
Georgia Department of Public Health

V. APPENDICES

APPENDIX A.
ILLUSTRATIONS

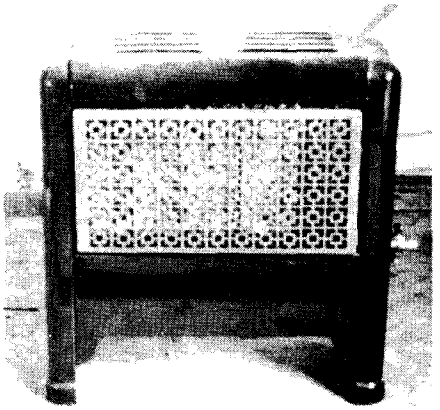


Figure 1. Heater A: radiant, unvented, enclosed.

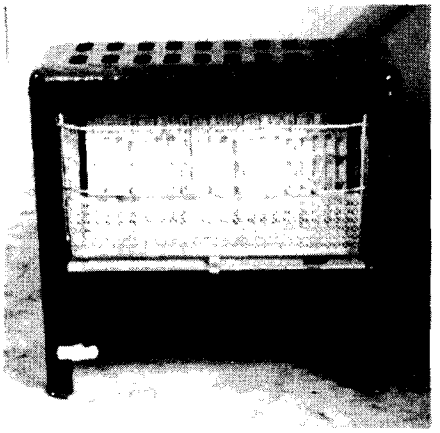


Figure 2. Heater B: radiant, unvented, open.

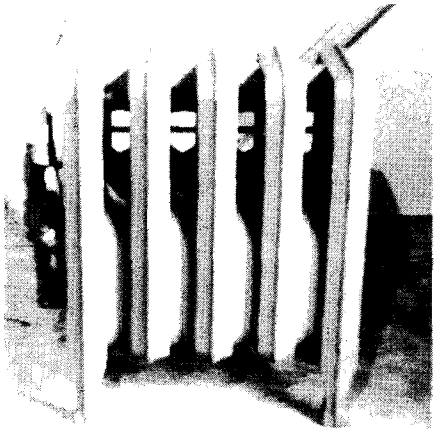


Figure 3. Heater C: steam radiator, unvented.

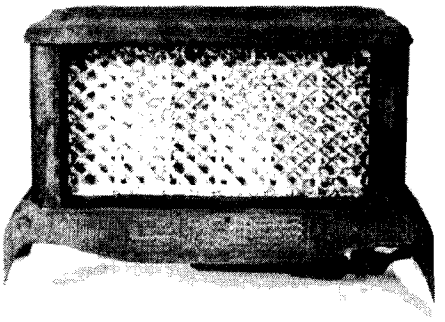


Figure 4. Heater D: radiant, unvented, open.

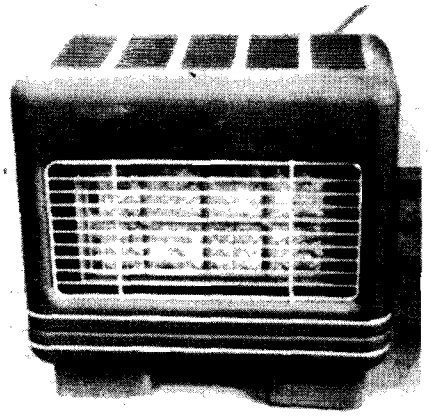


Figure 5. Heater E: radiant, vented, enclosed.

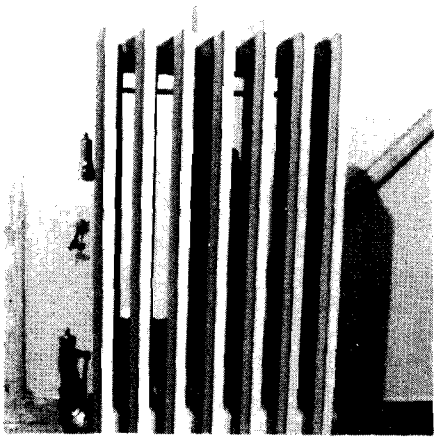


Figure 6. Heater F: steam radiator, vented.

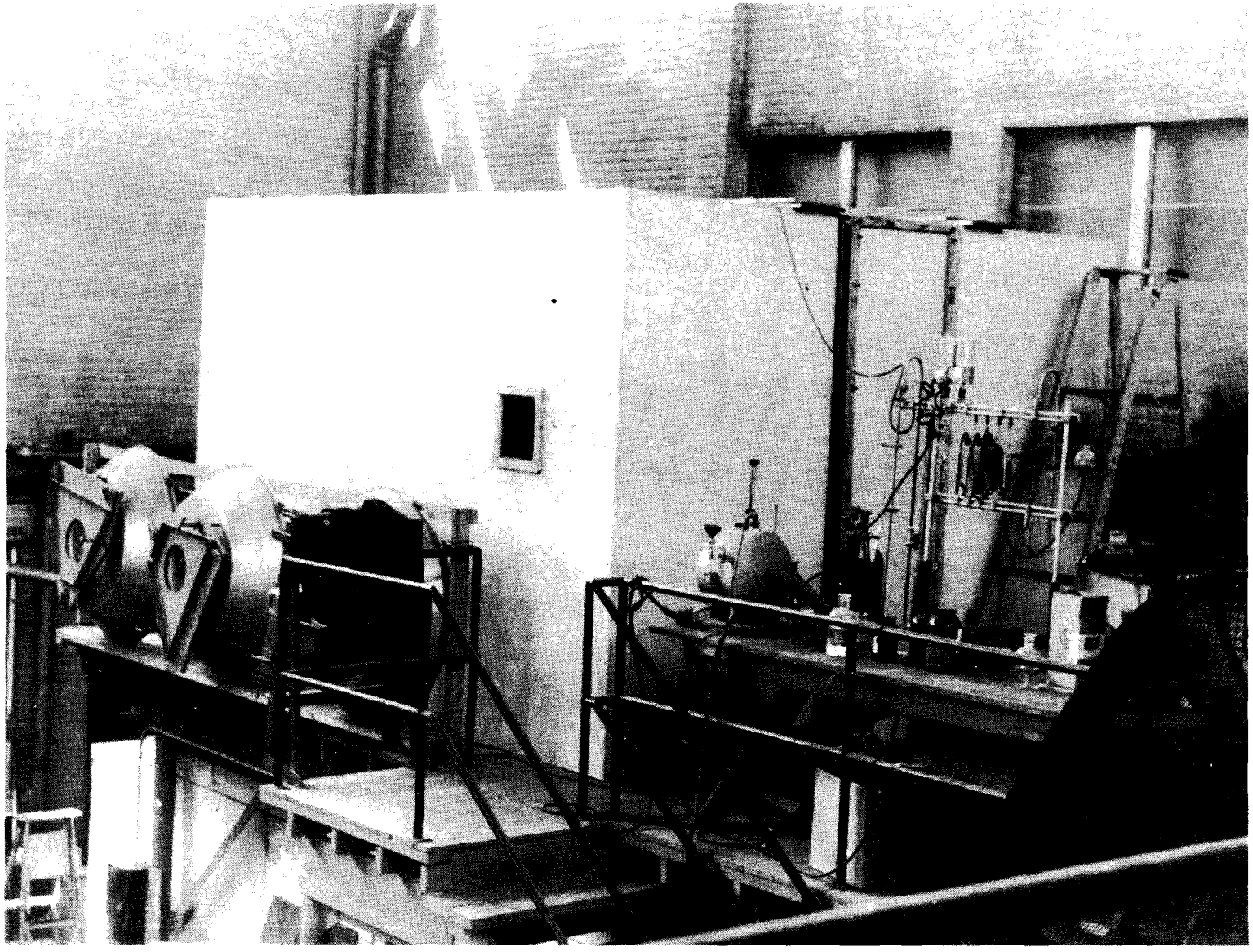


Figure 7. Outside View of the Room in Which the Heaters Were Tested and, Right, the Analytical Equipment Used.

APPENDIX B.
TABLES OF EXPERIMENTAL DATA

TABLE I

TEST DATA FOR HEATER A

Type heater: Radiant, unvented, enclosed. Fuel: Propane.
Rated input: 20,000 BTU/Hr. Actual input: 16,500 BTU/Hr.

Time (Hours)	BTU Input	Room Gas Analysis		
		CO_2	O_2	CO
		Run No. 1		
0	0	0%	20.9%	0%
1/2	8,200	1.5	19.3	Trace
1	16,100	1.9	18.4	0.001
1-1/2	24,500	3.0	17.0	0.005
2	32,500	3.7	16.2	0.01
2-1/2	40,800	4.2	15.2	0.04
3	49,100	4.3	15.0	0.04
3-1/2	57,600	4.6	14.4	0.06
4	65,700	4.7	13.9	0.06
4-1/2	74,000	5.2	14.3	0.06
5	82,300	4.9	13.9	0.08
5-1/2	90,600	5.1	14.0	0.08
6	98,900	5.2	13.7	0.08
6-1/2	107,200	5.0	14.0	0.10
		Run No. 2		
1/2	8,500	1.05	19.00	0.001
1	16,700	1.75	17.75	0.003
1-1/2	24,800	2.80	16.20	0.01
2	33,000	3.50	16.30	0.02
2-1/2	41,100	3.80	15.70	0.04
3	49,300	4.10	15.00	0.06
3-1/2	57,400	---	---	0.08
4	65,500	4.20	15.00	0.10
4-1/2	73,700	4.60	14.65	0.15
5	81,800	4.60	14.45	0.15
5-1/2	89,900	4.70	14.60	0.15
6	98,000	4.80	14.80	0.20

TABLE II

TEST DATA FOR HEATER B

Type heater: Radiant, unvented, open. Fuel: Propane.
Rated input: 24,000 BTU/Hr. Actual input: 25,200 BTU/Hr.

Time (Hours)	BTU Input	Room Gas Analysis		
		CO_2	O_2	CO
		Run No. 1		
0	0	0%	20.9%	0%
1/2	12,800	1.7	17.9	Trace
1	25,200	3.3	16.3	0.005
1-1/2	38,000	3.7	15.3	0.02
2	50,800	4.1	15.2	0.04
2-1/2	63,600	4.7	14.8	0.04
3	76,400	4.9	14.1	0.05
3-1/2	89,200	5.3	13.5	0.05
4-1/10*	114,300	5.6	13.2	0.05
		Run No. 2		
0	0	0	20.9	0
1/2	12,600	1.95	18.40	Trace
1	25,200	2.85	16.55	0.005
1-1/2	37,800	3.65	15.60	0.02
2	50,400	4.00	15.10	0.03
2-1/2	63,000	4.40	14.50	0.04
3	75,200	5.10	13.90	0.04
3-1/2	87,700	5.90	13.40	0.05
4-1/10*	102,000	6.00	13.20	0.05

*Flame out.

TABLE III

TEST DATA FOR HEATER C

Type heater: Steam, unvented. Fuel: Propane. Rated input: 15,000 BTU/Hr. starting. Actual input: 8,400 BTU/Hr. running.

Time (Hours)	BTU Input	Room Gas Analysis		
		CO_2	O_2	CO
1	8,000	0.9%	19.5%	0%
2	20,200	1.4	18.5	Trace
3	29,000	2.0	18.2	Trace
4	37,500	2.0	18.1	Trace
5	48,400	7.8	18.0	Trace
6	56,900	2.1	18.0	Trace
7	65,300	2.0	18.0	0.001
8	74,100	1.4	18.1	0.001
9	83,000	1.4	18.0	0.001
10	90,300	2.0	17.9	0.001
11	101,000	2.0	17.9	0.001
12	108,500	1.8	17.8	0.001
13	117,600	1.5	17.3	0.001
14	126,000	1.4	17.6	0.001
15	134,200	1.3	17.8	0.001
16	142,400	1.3	17.9	0.001
17	150,700	2.1	18.0	0.001
18	159,000	2.3	18.0	0.001
19	167,300	2.1	17.5	0.001
20	175,100	2.7	17.4	0.001
21	183,600	3.0	17.2	0.001
22	191,100	No Sample	No Sample	No Sample
23	199,600	No Sample	No Sample	No Sample
24	208,100	3.7	16.5	0.004

TABLE IV

TEST DATA FOR HEATER D

Type heater: Radiant, unvented, open front. Fuel: Natural gas.
Rated input: 24,000 BTU/Hr. Actual input: 27,200 BTU/Hr.

Time (Hours)	BTU Input	Room Gas Analysis CO_2	O_2	CO
		Run No. 1		
1/2	12,700	1.1%	18.8%	0.04%
1	26,900	2.0	17.2	0.08
1-1/2	41,100	2.8	16.2	0.20
2	55,300	3.2	15.5	0.30
2-1/2	69,400	3.8	15.3	0.35
3	83,500	3.6	15.3	0.40
3-1/2	97,600	3.8	14.9	0.40
4	101,700	3.7	15.1	0.35
4-1/2	115,900	4.4	14.6	0.40
5	130,000	3.8	14.6	0.45
5-1/3*	147,700	4.1	14.3	0.45
		Run No. 2		
1/2	14,200	1.7	18.2	0.04
1	27,400	2.8	16.7	0.08
1-1/2	40,700	2.8	15.9	0.12
2	54,100	3.4	14.4	0.28
2-1/2	67,500	3.7	15.4	0.36
3	81,000	3.7	15.1	0.34
3-1/2	94,600	3.7	14.9	0.36
4	108,200	3.6	15.4	0.34
4-1/2	121,900	3.7	14.8	0.40
5	135,600	4.2	14.4	0.40
5-1/2	149,400	3.6	15.1	0.45
5-3/4*	156,700	4.2	14.4	0.50

*Flame out.

TABLE V

TEST DATA FOR HEATER E

Type heater: Radiant, vented, enclosed. No vent connected to heater.
Gas: Propane. Rated input: 20,000 BTU/Hr. Actual input: 14,500 BTU/Hr.

Time (Hours)	BTU Input	Room Gas Analysis		
		CO_2	O_2	CO
0	0	0%	20.9%	0%
1/2	7,750	1.1	19.2	0.001
1	14,500	1.8	18.4	0.002
1-1/2	22,200	2.1	17.8	0.015
2	30,000	2.9	17.1	0.03
2-1/2	37,700	3.0	16.7	0.04
3	45,500	3.1	16.6	0.04
3-1/2	53,200	3.9	15.9	0.06
4	61,000	3.5	15.8	0.06
4-1/2	68,700	3.7	15.7	0.08
5	76,500	3.7	15.8	0.10
5-1/2	84,200	3.8	15.4	0.10
6	92,000	3.8	15.5	0.10

TABLE VI

TEST DATA FOR HEATER E

Type heater: Radiant, vented, enclosed. Two feet of vent missing.
Gas: Propane. Rated input: 20,000 BTU/Hr. Actual input: 21,400 BTU/Hr.

Time (Hours)	BTU Input	Room Gas Analysis			Remarks
		CO_2	O_2	CO	
0	0	0%	20.9%	0%	Vent pipe lifted
1/2	9,750	1.2	19.3	0.01	from collar on
1	20,900	2.3	17.9	0.04	heater, leaving
1-1/2	32,100	3.5	16.2	0.06	two feet of air
2	43,300	3.5	16.1	0.10	space from collar
2-1/2	54,300	3.6	16.0	0.10	to vent.
3	65,400	3.7	15.9	0.15	
3-1/2	76,400	3.8	15.7	0.15	
4	87,500	4.0	15.1	0.20	
4-1/2	97,400	4.0	15.2	0.30	
5	118,400	3.9	15.4	0.35	
5-1/2	128,300	3.9	15.7	0.35	

TABLE VII

TEST DATA FOR HEATER E

Type heater: Radiant, vented, enclosed. Vented outside room.
Gas: Propane. Rated input: 20,000 BTU/Hr. Actual input: 20,800 BTU/Hr.

Time (Hours)	BTU Input	Room Gas Analysis CO_2	O_2	CO	Remarks
		Run No. 1			
0	0	0 %	20.9%	0%	Flue gas CO = 0.01%
1/2	11,200	0	20.7	Trace	CO less than 0.001%
1	21,700	0	20.7	"	
1-1/2	32,200	0.2	20.7	"	
2	42,800	0.1	20.5	"	
2-1/2	53,400	0.0	20.5	"	
3	63,700	0.0	20.4	"	Flue gas CO = 0.01%
3-1/2	74,200	0.0	20.8	"	
4	84,500	0.0	20.5	"	
4-1/2	94,700	0.0	20.8	"	Flue gas CO = 0.01%
5	104,900	0.0	20.5	"	
5-1/2	115,100	0.0	20.5	"	
6	125,200	0.0	20.9	"	
6-1/2	135,400	0.0	20.8	"	
7	145,600	0.0	20.6	0.001	Flue gas CO = 0.005%
7-1/2	155,800	0.0	20.6	0.001	
8	165,900	0.0	20.8	0.001	
		Run No. 2			
1/2	10,700	0	20.9	Trace	Room recaulked
1	21,400	0	20.8	"	Vent CO = 0.005%
1-1/2	32,100	0.1	20.8	"	
2	42,800	0.0	20.9	"	
2-1/2	53,500	0.1	20.6	"	
3	64,200	0.3	20.9	"	Vent CO = 0.005%
3-1/2	74,900	0.2	20.5	"	
4	85,600	0.3	20.4	"	
4-1/2	96,300	0.0	20.7	"	
5	107,000	0.2	20.7	"	
5-1/2	117,700	0.2	20.7	"	Vent CO = 0.005%
6	128,400	0.1	20.7	"	
6-1/2	139,100	0.3	20.4	"	
7	149,800	0.2	20.6	"	
7-1/2	160,500	0.3	20.6	"	
8	171,200	0.1	20.8	"	Vent CO = 0.005%

TABLE VIII*

TEST DATA FOR HEATER E

Type heater: Radiant, vented, enclosed. Vented. Gas: Propane. Rated input: 20,000 BTU/Hr. Actual input: 20,200 BTU/Hr.

Time (Hours)	BTU Input	Room Gas Analysis			Remarks
		CO_2	O_2	CO	
1	19,800	0.0%	20.9%	0%	Vent CO = 0.005%
2	36,600	0.0	20.9	Trace	
3	59,400	0.2	20.7	"	
4	79,200	0.1	20.7	"	Vent CO = 0.005%
5	99,000	0.1	20.7	"	
6	118,800	0.1	20.8	"	
7	138,600	0.2	20.6	"	
8	158,400	0.1	20.6	"	Vent CO = 0.005%
9	178,200	0.1	20.7	"	
10	198,000	0.1	20.7	"	
11	217,000	0.0	20.8	"	
12	237,600	0.0	20.6	"	Vent CO = 0.005%
13	256,400	0.1	20.8	"	
14	276,200	0.0	20.7	"	
15	296,000	0.1	20.8	"	
16	315,800	0.1	20.8	"	Vent CO = 0.005%
17	335,600	0.1	20.7	"	
18	355,400	0.1	20.8	"	
19	375,200	0.0	20.7	"	Vent CO = 0.005%
20	395,000	0.0	20.6	"	
21	414,800	0.2	20.7	"	
22	434,600	0.2	20.7	"	
23	454,400	0.1	20.8	"	
24	475,000	0.1	20.7	"	Vent gas analysis: CO = 0.005%, CO_2 = 4.0%, O_2 = 14.6%.

*No plot of this data is included in this report.

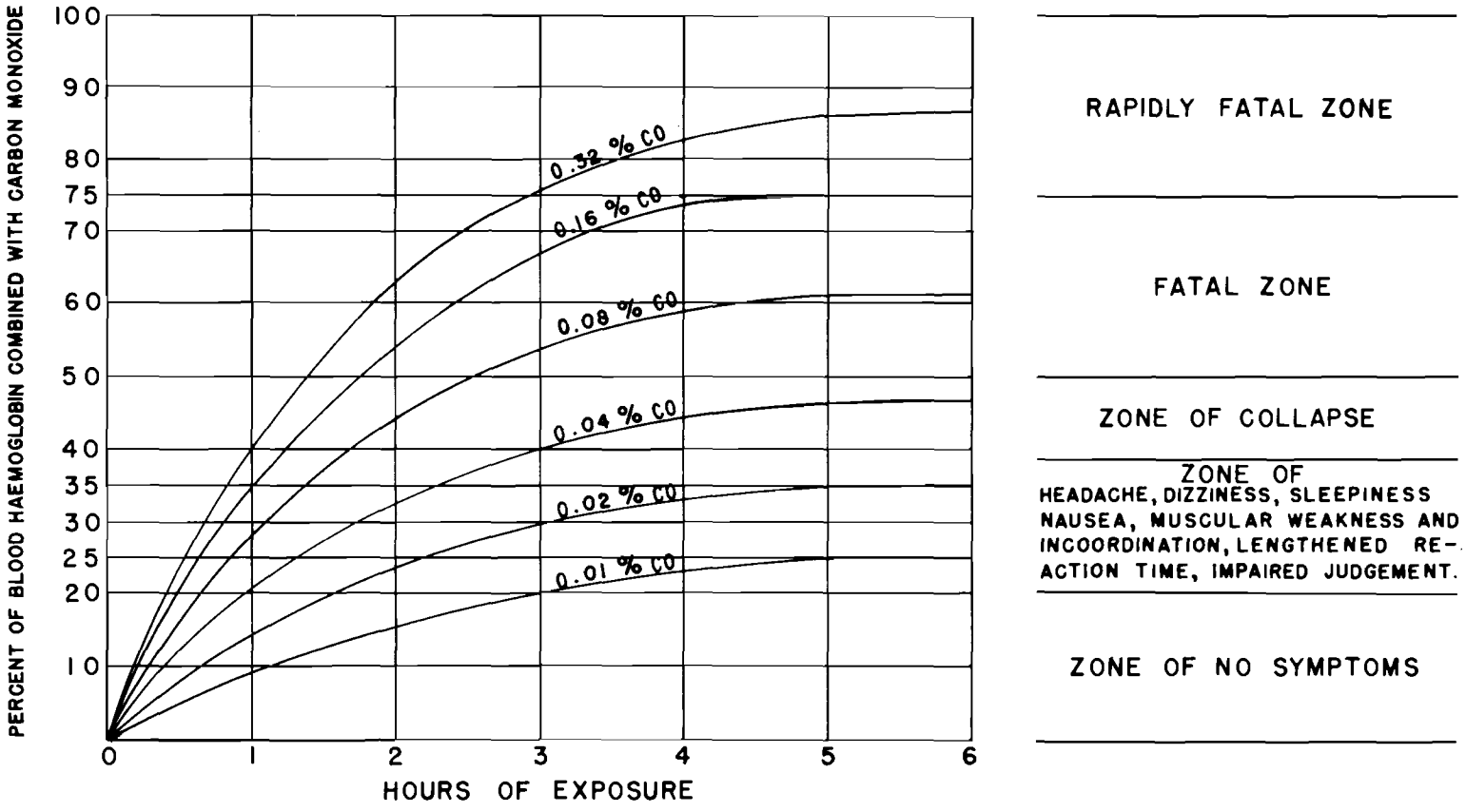
TABLE IX

TEST DATA FOR HEATER F

Type heater: Steam, vented. Gas: Propane. Rated input: 18,000 BTU/Hr. starting. Actual input: 10,700 BTU/Hr. running.

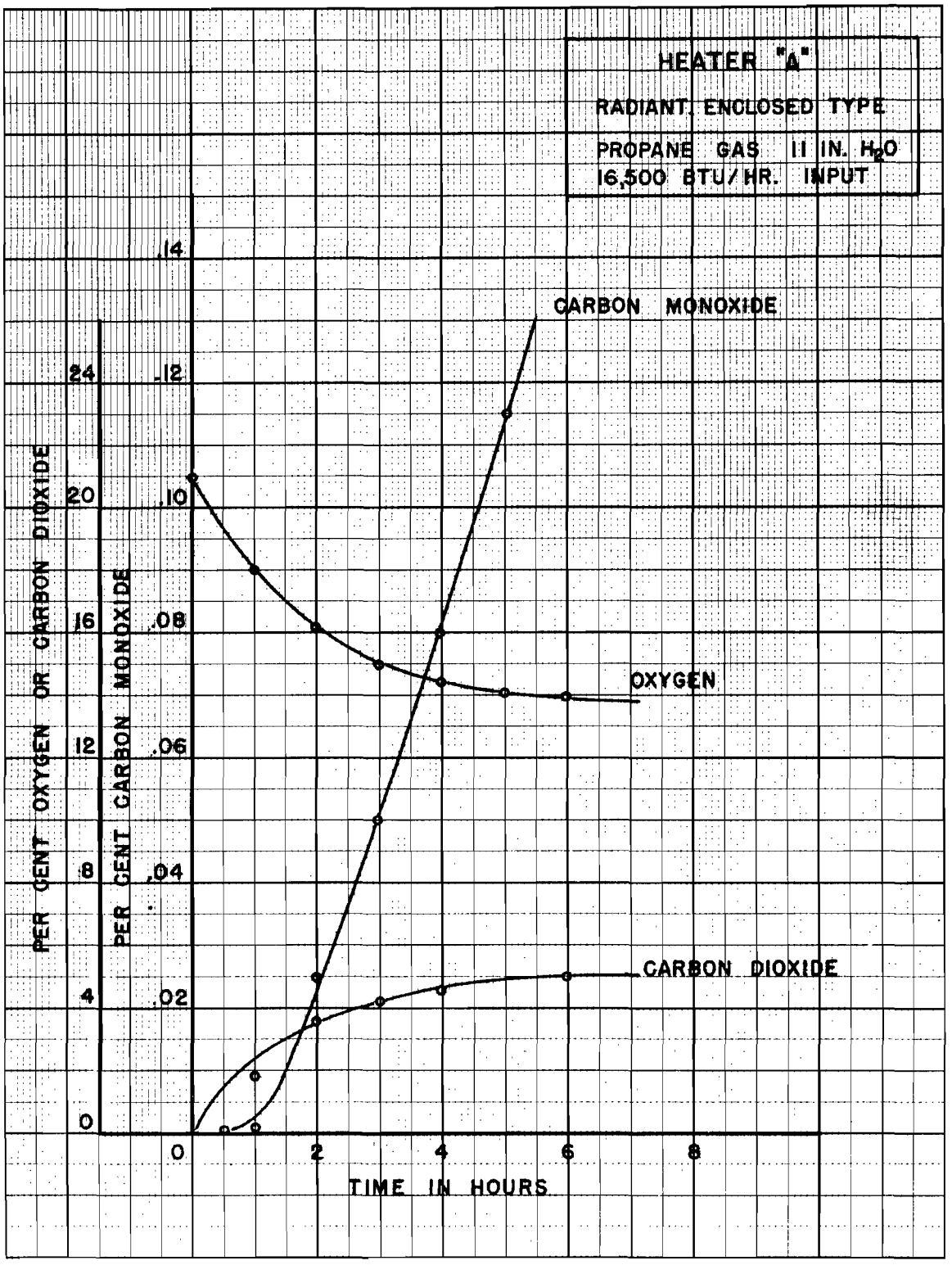
Time (Hours)	BTU Input	Room Gas Analysis			Remarks
		CO_2	O_2	CO	
1	16,100	0.5%	20.4%	Trace%	Flue gas CO = 0.001%
2	27,600	0.8	20.1	"	
3	38,900	0.2	20.7	"	
4	50,000	0.2	20.6	"	
5	60,800	0.2	20.3	"	Flue gas CO = 0.001%
6	72,100	0.1	20.7	"	
7	83,300	0.0	20.7	"	
8	94,400	0.0	20.6	"	
9	105,500	0.2	20.6	"	Flue gas CO = 0.001%
10	116,600	0.2	20.6	"	
11	127,800	0.2	20.7	"	
12	138,900	0.2	20.6	"	
13	150,000	0.3	20.5	"	Flue gas CO = 0.001%
14	160,800	0.3	20.4	"	
15	171,900	0.1	20.6	"	
16	183,100	0.3	20.7	"	
17	194,200	0.3	20.6	"	Flue gas CO = 0.001%
18	206,500	0.3	20.5	"	
19	217,400	0.2	20.8	"	
20	228,600	0.0	20.8	"	
21	239,500	0.3	20.5	"	Flue gas CO = 0.001%
22	250,600	0.2	20.7	"	
23	261,800	0.1	20.7	"	
24	262,800	0.1	20.7	"	

EFFECT OF CARBON MONOXIDE INHALATION

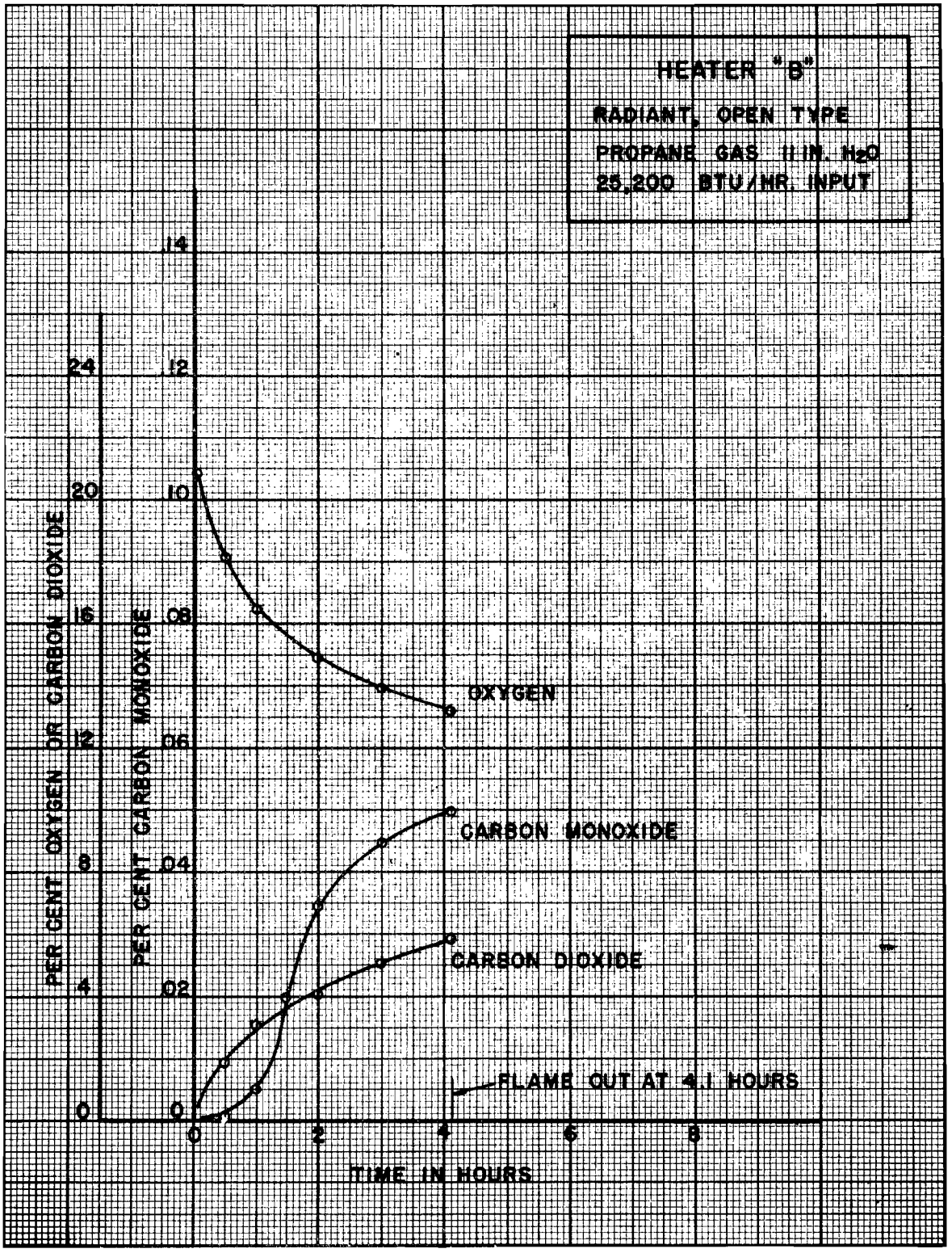


GEORGIA DEPARTMENT OF PUBLIC HEALTH

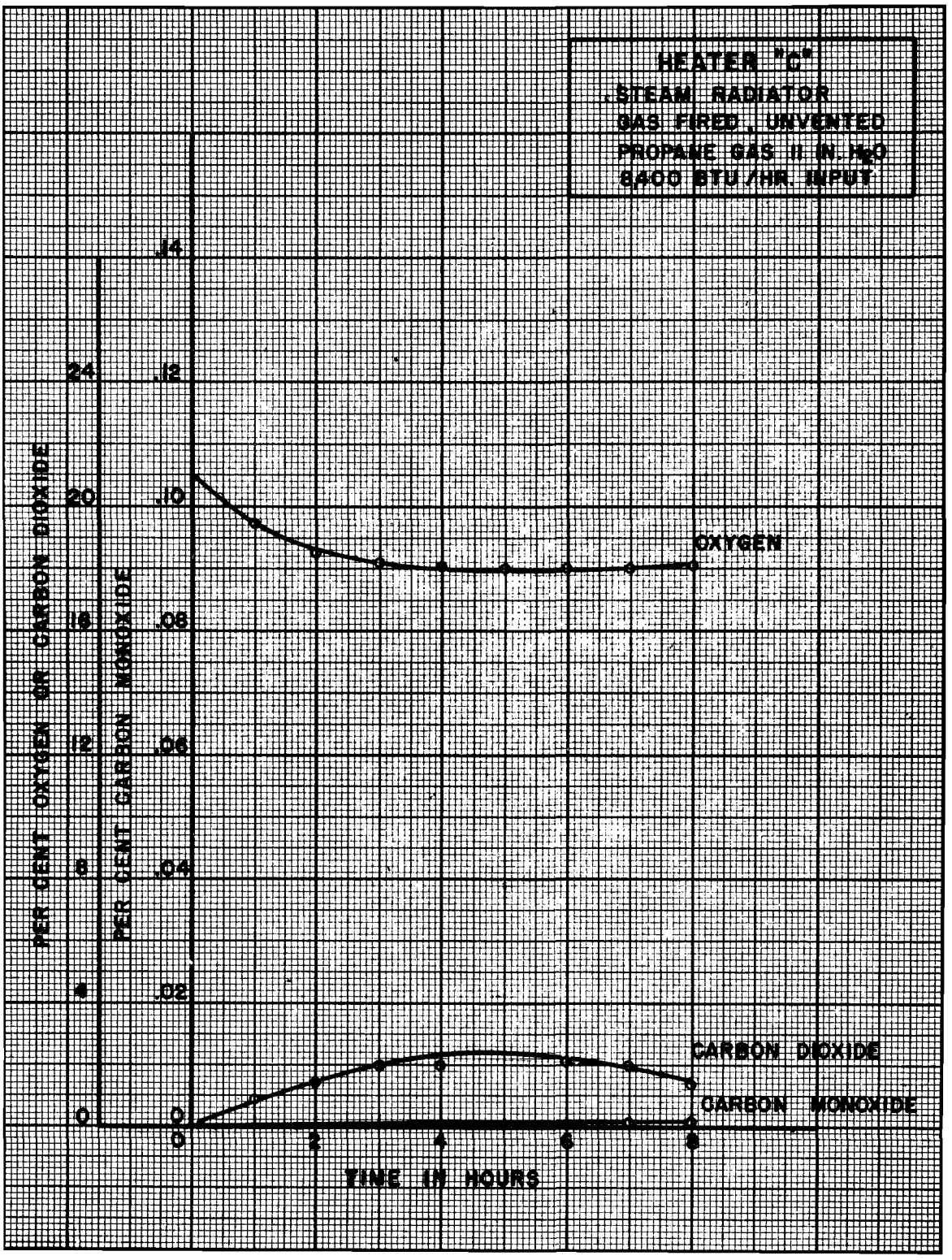
Plot 1.


HEATER "A"
RADIANT ENCLOSED TYPE
PROPANE GAS 11 IN. H_2O
16,500 BTU/HR. INPUT
CARBON MONOXIDE
OXYGEN
CARBON DIOXIDE
PER CENT OXYGEN OR CARBON DIOXIDE
PER CENT CARBON MONOXIDE
TIME IN HOURS
0
4
8
12
16
20
24
.02
.04
.06
.08
.10
.12
.14
0
2
4
6
8

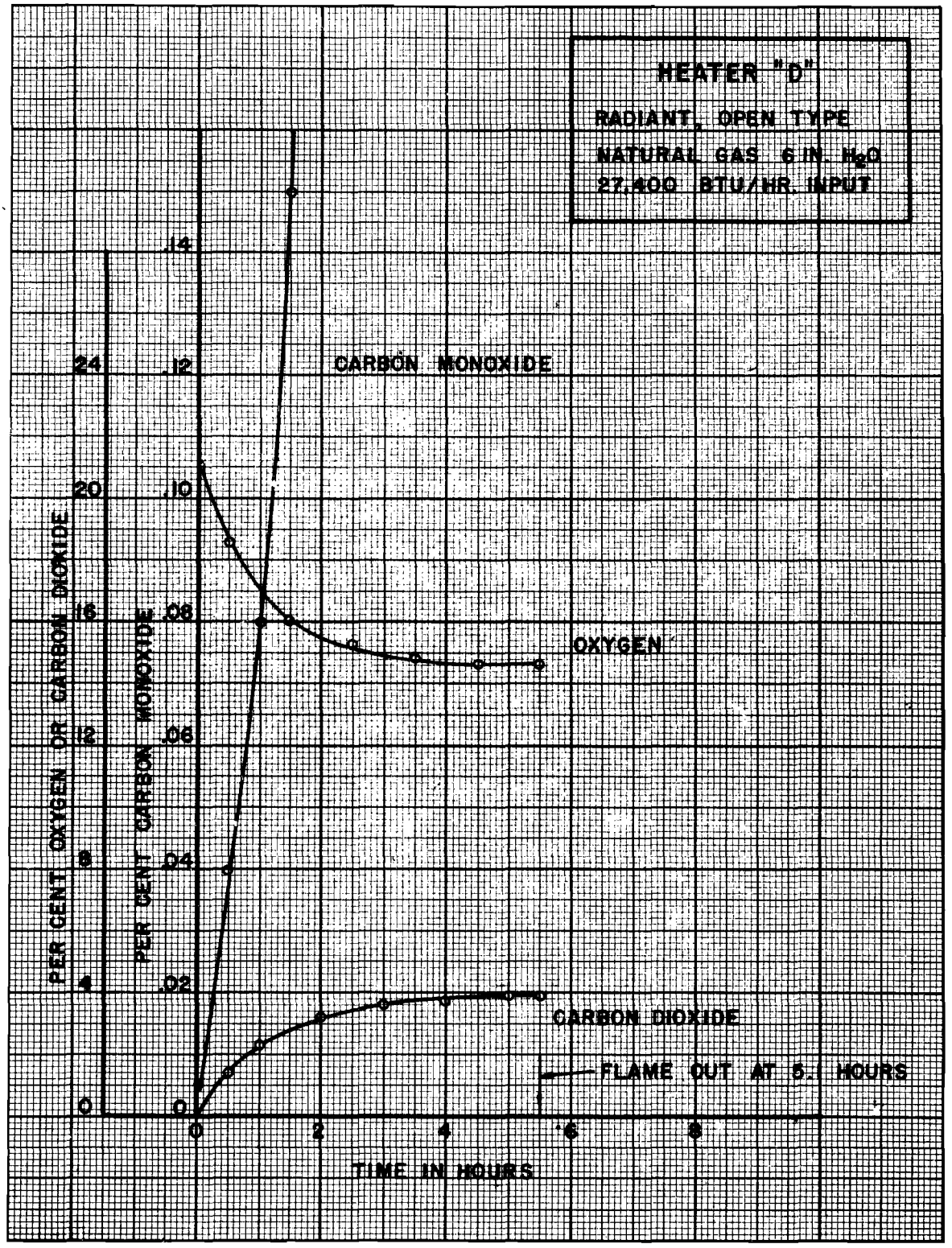
Plot 2.


HEATER "B"
RADIANT, OPEN TYPE
PROPANE GAS 11 IN. H2O
25,200 BTU/HR. INPUT
PER CENT OXYGEN OR CARBON DIOXIDE
PER CENT CARBON MONOXIDE
24
20
16
12
8
4
0
14
12
10
08
06
04
02
0
OXYGEN
CARBON MONOXIDE
CARBON DIOXIDE
FLAME OUT AT 4.1 HOURS
0
2
4
6
8
TIME IN HOURS

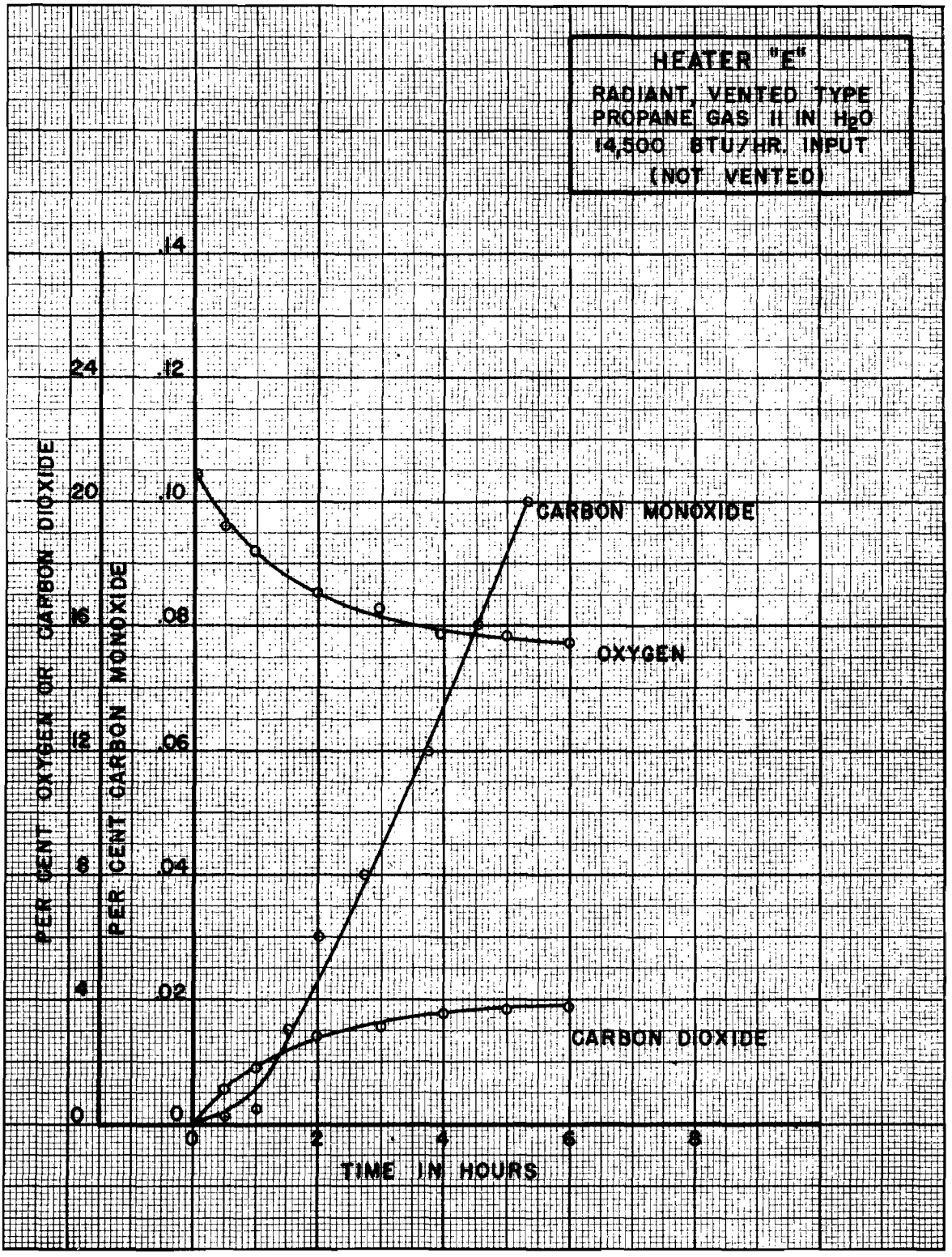
Plot 3.


HEATER "C"
STEAM RADIATOR
GAS FIRED, UNVENTED
PROPANE GAS 11 IN. H_2O
8400 BTU/HR. INPUT
PER CENT OXYGEN OR CARBON DIOXIDE
PER CENT CARBON MONOXIDE
24
20
16
12
8
4
0
.14
.12
.10
.08
.06
.04
.02
0
OXYGEN
CARBON DIOXIDE
CARBON MONOXIDE
0
2
4
6
8
TIME IN HOURS

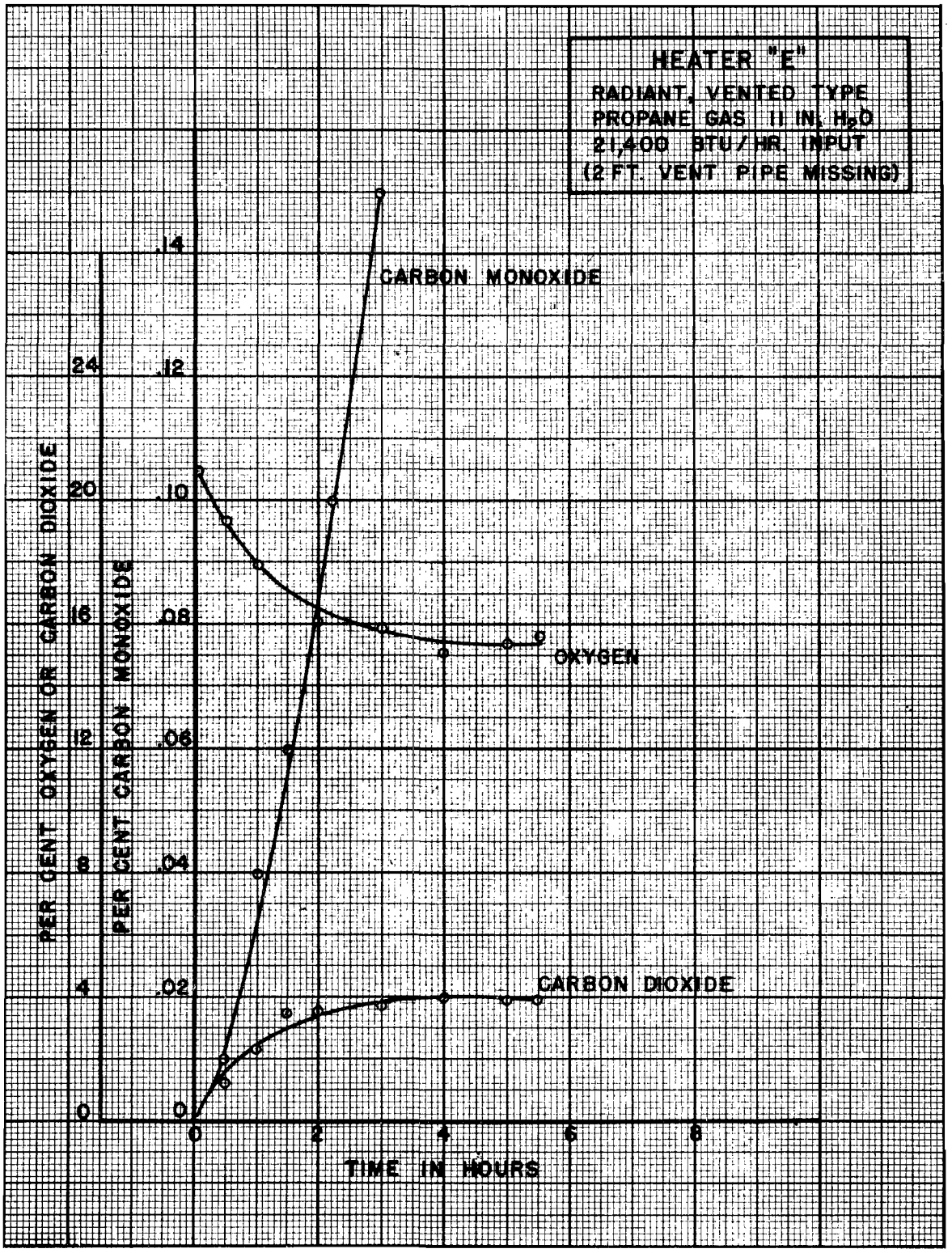
Plot 4.


HEATER "D"
RADIANT, OPEN TYPE
NATURAL GAS 6 IN. H_2O
27,400 BTU/HR. INPUT
CARBON MONOXIDE
OXYGEN
CARBON DIOXIDE
FLAME OUT AT 5.1 HOURS
PER CENT OXYGEN OR CARBON DIOXIDE
PER CENT CARBON MONOXIDE
TIME IN HOURS
24
20
16
12
8
4
0
.14
.12
.10
.08
.06
.04
.02
0
2
4
6
8

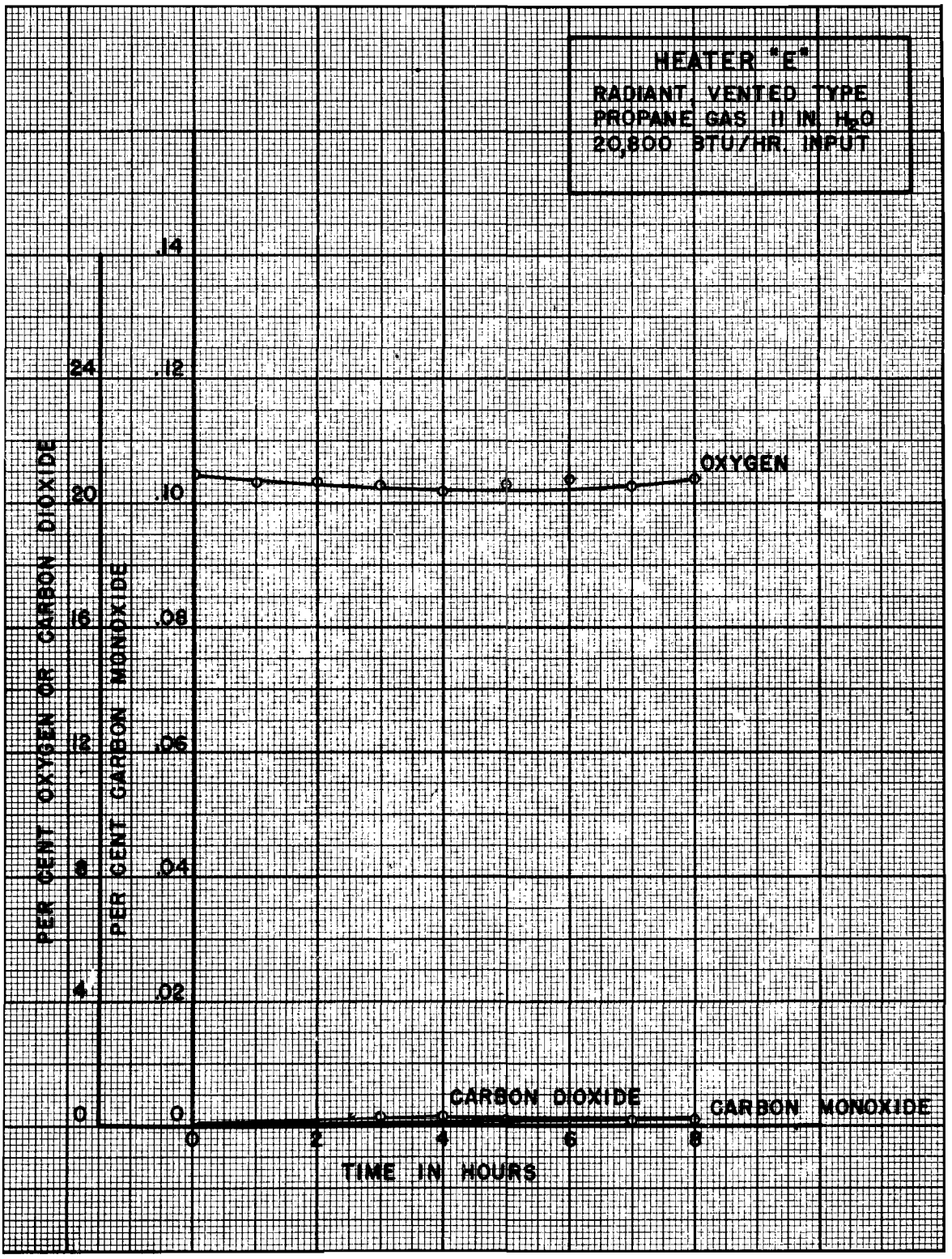
Plot 5.


HEATER "E"
RADIANT, VENTED TYPE
PROPANE GAS 11 IN H_2O
14,500 BTU/HR. INPUT
(NOT VENTED)
PER CENT OXYGEN OR CARBON DIOXIDE
PER CENT CARBON MONOXIDE
24
20
16
12
8
4
0
.14
.12
.10
.08
.06
.04
.02
0
CARBON MONOXIDE
OXYGEN
CARBON DIOXIDE
0
2
4
6
8
TIME IN HOURS

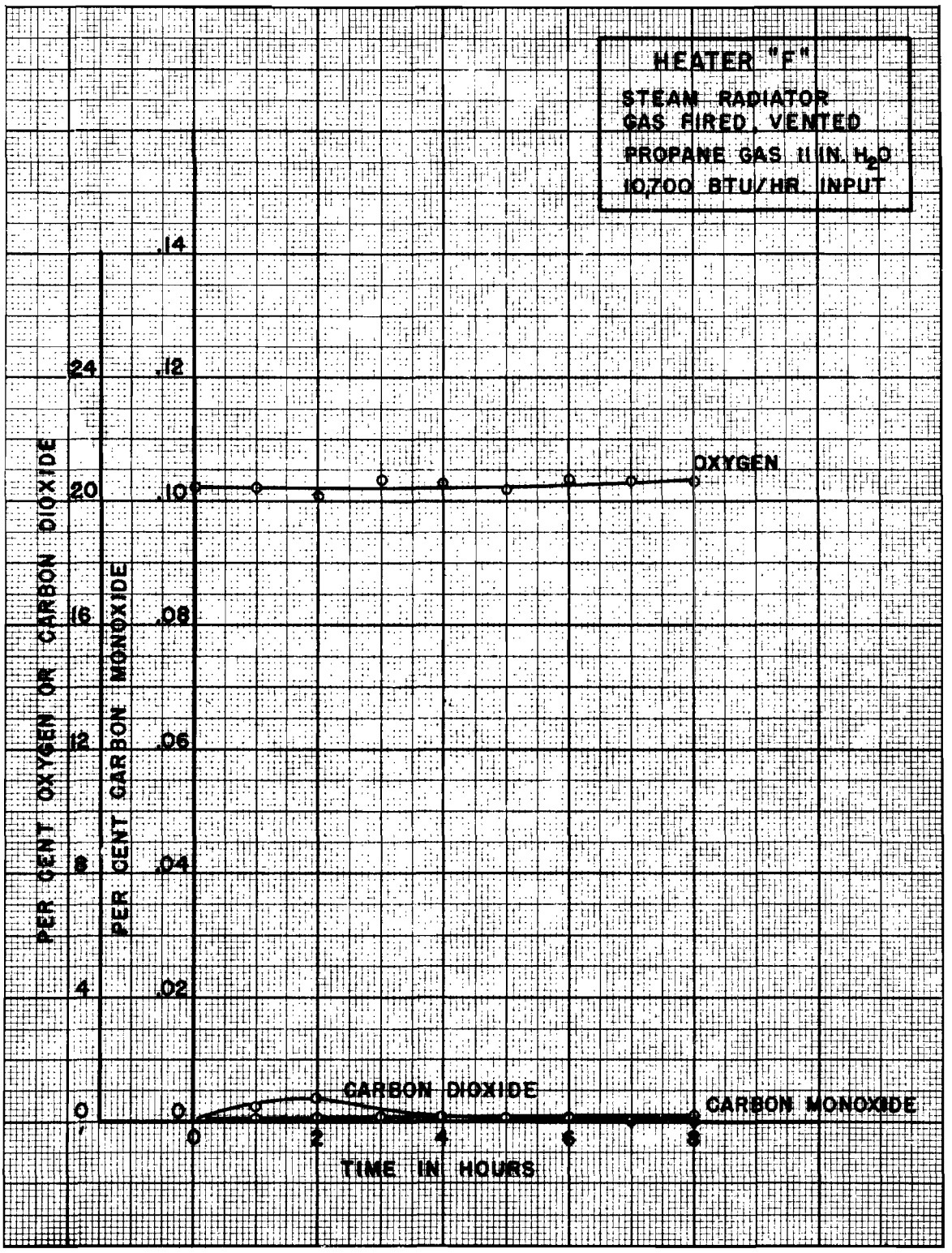
Plot 6.


HEATER "E"
RADIANT, VENTED TYPE
PROPANE GAS 11 IN. H_2O
21,400 BTU/HR. INPUT
(2 FT. VENT PIPE MISSING)
CARBON MONOXIDE
OXYGEN
CARBON DIOXIDE
PER CENT OXYGEN OR CARBON DIOXIDE
PER CENT CARBON MONOXIDE
TIME IN HOURS
0
4
8
12
16
20
24
.02
.04
.06
.08
.10
.12
.14
0
2
4
6
8

Plot 7.


HEATER "E"
RADIANT, VENTED TYPE
PROPANE GAS 11 IN. H_2O
20,800 BTU/HR. INPUT
PER CENT OXYGEN OR CARBON DIOXIDE
PER CENT CARBON MONOXIDE
24
20
16
12
8
4
0
.14
.12
.10
.08
.06
.04
.02
0
OXYGEN
CARBON DIOXIDE
CARBON MONOXIDE
0
2
4
6
8
TIME IN HOURS

Plot 8.


HEATER "F"
STEAM RADIATOR
GAS FIRED, VENTED
PROPANE GAS 11 IN. H_2O
10,700 BTU/HR. INPUT
PER CENT OXYGEN OR CARBON DIOXIDE
PER CENT CARBON MONOXIDE
24
20
16
12
8
4
0
.14
.12
.10
.08
.06
.04
.02
0
OXYGEN
CARBON DIOXIDE
CARBON MONOXIDE
0
2
4
6
8
TIME IN HOURS

Plot 9.

APPENDIX D

BIBLIOGRAPHY

(1) Jones, G. W., Yant, W. P., and Berger, L. B., Combustion Products from a Radiant-Type Natural Gas Heater and Suggestions Regarding Its Operation. U. S. Bureau of Mines, Report of Investigations No. 2443, 1923.

(2) Jones, G. W., Berger, L. B., and Holbrook, W. F., Carbon Monoxide Hazards from House Heaters Burning Natural Gas. U. S. Bureau of Mines, Technical Paper No. 337, 1923.

(3) Jones, G. W., Jant, W. P., and Berger, L. B., Incomplete Combustion in Natural Gas Space Heaters. U. S. Bureau of Mines, Technical Paper No. 362, 1925.

(4) "Carbon Monoxide." Public Health Reports 56, No. 10, 421-33 (1941).

(5) Beck, H. G., Roetman, E. T., and Suter, G. M., Combustion Products Study. West Virginia University, Bulletin No. 4, August, 1942.